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A SOLID STATE DIRECTIONAL GAMMA DETECTOR

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ABSTRACT

A solid-state gamma-ray detector has been developed which exhibits directionality. Four PIN diode detectors are backed with Pb and arranged in a square array which exhibits an angular response to gamma rays. The high-Z material provides directionality and also enhances the sensitivity of the detectors to high-energy gammas by means of the x-ray fluorescence accompanying photon interactions in the backing. The array responses are used to identify the quadrant containing the source and obtain the radiation level. Ratios of the counting rates in opposite pairs of detectors are used to determine the angular position of the source within the quadrant.

INTRODUCTION

The availability of PIN diode detectors¹ with reasonable sensitivity to x-rays and low-energy gamma rays has made possible the development of convenient, low-power, portable radiation-measuring instruments. The addition of microprocessor control leads to a class of hand-held instruments which are capable of identifying and measuring radiation sources automatically under a wide variety of conditions. This capability can be greatly extended, as in the

Radiation Mapping System (Ranger)² developed at Los Alamos, by telemetering radiation levels measured by such instruments to a ranging system capable of directly plotting the radiation contours of a site being surveyed. In this and other applications, it would be very beneficial to have a detector capable of rapidly and conveniently determining both the radiation level and the direction to the source being detected. While collimated detectors can be used in this application, it would be advantageous to have a detector capable of measuring both the radiation intensity and the direction of the source in a single acquisition cycle. The device described below is a prototype capable of doing this, and is sufficiently light, low-powered and small to be produced as a self-contained hand-held field instrument. The computations required to obtain directional information from the detector count rates can be handled by the microcomputer used to manage the other functions of such portable instruments.

THE DETECTOR ARRAY

The accurate location of a gamma-ray source by means of a single detector required a collimator with sufficiently narrow acceptance angle to satisfy the particular resolution requirements. In contrast, if one uses an array of detectors, each one is required to exhibit only a modest angular response and front/back ratio, provided all counts can simultaneously be acquired and used in a computation of the position of the source. Because of the availability of PIN diodes with reasonable sensitivities, it is feasible to build such an array which is suitable for field-portable use.

Our prototype detector consists of a planar array of PIN diodes mounted on the faces of a Pb cube. Two versions have been constructed. The first consisted of 4 PIN diodes on the faces of a 1 cm cube. The second version has 4 PIN diodes on each face of a hollow Pb cube. In both cases, the Pb thickness is 1 cm which, for ^{60}Co gamma rays, provides a front/back ratio of approximately 3 for opposing detectors. The second version is shown in Fig. 1. The Pb cube is partly hidden under the teflon mounting plate, and it is inserted into the detector package which has the PIN diodes mounted on the inside surfaces of the teflon block. The angular response function for each detector is approximated quite well by a biased $\cos^2(\theta/2)$ function.

The sensitivity of PIN diodes decreases rapidly with energy, but it can be enhanced at higher energies by backing the diodes with a high-Z material. Measurements of the sensitivity of the PIN diodes as a function of the thickness of the high-Z backing show a significant enhancement of the intrinsic diode sensitivity for gamma-ray energies above 100 keV. This enhancement is provided by the x-ray fluorescence accompanying the gamma-ray interactions in the attenuator which, in the case of Pb, is at 72 KeV, and by low-energy backscattered Compton photons. This response is illustrated in Fig. 2, which shows the pulse height spectra for ^{57}Co and ^{60}Co sources. Both spectra show the enhancement at 72 keV due to fluorescence in the backing. For gamma-ray energies above 100 keV, this enhancement reaches a factor of 2 at about 1 cm thickness of Pb. Since the diode sensitivity rises sharply below 80 keV, a lighter attenuating material may prove to be advantageous.

ELECTRONICS AND COMPUTATIONS

The electronics package constructed to implement this scheme consists of two units for the detector and signal processing electronics connected via a serial port to a small microcomputer which implements the directional algorithm and displays the results graphically. It was expedient to separate the analog and digital sections of the signal processing electronics because of the high noise sensitivity of the charge-sensitive amplifiers used to amplify the signal from the detectors.

The detector package contains the detectors and associated analog electronics. Each of the four sides of the detector consists of 4 PIN diodes paired into two charge-sensitive preamplifiers which are summed by a simple two-stage RC shaping amplifier. Due to the small charge generated in each detector, it was found necessary to preselect the input FETs for each preamplifier for low noise characteristics and to adjust the amplifier chains for roughly equivalent gains.

Measurements of the effects of paralleling PIN diodes into a single preamplifier show that the charge generated by an event in a single diode is partially diverted by the paralleled junctions. The reduction in gain degrades the signal-to-noise ratio. In the interest of increasing sensitivity, while minimizing electronics and preserving a reasonable signal-to-noise ratio, it was found that 2 diodes connected to a preamplifier was nearly optimum. The circuit board containing the preamplifiers and shaping amplifiers was constructed as an integral part of the detector package to minimize

microphonic noise. This detector package and the associated microprocessor board and power source are shown in Fig. 1.

The digital electronics package consists of a microprocessor which communicates the counts to the microcomputer which are accumulated in 4 counters during a variable acquisition period. The 4 analog signals from the detector package are shaped and discriminated by comparators which connect to the counters. Thus, each acquisition cycle results in 4 separate count totals for the 4 individual faces. In our prototype instrument, these 4 counts are sent via a RS232 line to a small microcomputer for computation and graphic display. (These tasks could easily be handled in a Violinist³ package of the type used in many of our portable instruments and the results displayed on a large liquid crystal graphics display designed specifically for this application.) The software performs essentially three tasks: First, the 4 counts are compared and the quadrant facing the source is identified. Totalizing the counts provides a measurement of the intensity being received from this quadrant. Second, the counts are identified in pairs as belonging to the detectors most nearly aligned along the source direction and those transverse to this direction. The ratios of these pairs of counts are then calculated. Third, these two ratios are compared with a look-up table containing ratios measured from the angular response of the detector array and the angles identified for these two ratios. Because of statistics, these two angles rarely agree exactly, so a weighted average is taken which takes into account the reduced sensitivity to angle of the count ratio as the source position approaches a direction normal to one

face. (In effect, the two side detectors determine the angle when the source is normal to a face.) This average angle and the measured intensity are used to produce a logarithmic polar plot identifying the source direction with respect to the array.

DISCUSSION

The prototype detector described here has been set up to provide angular detection of ^{60}Co (and, with less accuracy, ^{137}Cs) gamma rays. Its characteristics are such that straightforward design modifications should make it generally applicable to a range of energies. The angular response of the array depends upon gamma-ray energy, and its sensitivity is a strong function of energy as well. Since the detector pulse-height spectrum contains very little energy information, some means of determining the appropriate angular function for the gamma energy being detected is necessary. One approach which we are investigating is to shim the detector package so that all gamma-ray energies over a range of interest produce essentially the same angular function. This procedure may also improve the energy response of the array. On the other hand, the storage of several sets of angular functions appropriate to several different energy ranges presents no problem. One way to obtain energy information about the gamma field being measured would be to use a fifth detector which has some energy resolution to provide the constants needed (from counts in several ROIs) to use the appropriate angular functions and electronically shim the detector response. Another more direct method would be to use an array constructed from detectors which exhibit energy resolution and then calculate the

angular ratios separately in each of several energy ranges. This scheme, if implemented with scintillation detectors, would extend the sensitivity of the device to background levels and might be capable of locating several sources of distinctly different gamma-ray energy. An attractive way to do this is to use CsI scintillators coupled to photodiodes, and we are presently investigating this approach.

Experience with this prototype shows that counting statistics of approximately 10% is sufficient to result in an angular definition of plus or minus 10 degrees, with precision increasing as the statistics improve. In order to provide as much precision as possible, an exponential running average is kept for each count, so the indicated angular direction changes gradually over several acquisition cycles. The sensitivity of the detector is such that (for ^{60}Co) a field of 1 mR/hr produces an average of 20 cps. We anticipate that a detector constructed with CsI scintillators and PIN diodes would be significantly more sensitive while providing the energy resolution to allow us to obtain angular discrimination over a wider range of gamma-range energies.

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REFERENCES

1. Hamamatsu Corp., 420 South Ave., Middlesex, New Jersey 08846.
2. G. M. Worth, J. M. Crowell, A. D. Meddles, J. D. Jarrett, M. A. Wolf, C. J. Umbarger, and Chris Moyer, IEEE Trans. Nucl. Sci. NS-32 (1984) 957.
3. Michael A. Wolf and Hugh C. Staley, IEEE Trans. Nucl. Sci. NS-32 (1984) 82.

FIGURE CAPTIONS

Fig. 1. Disassembled view of the instrument.

Fig. 2. Spectral response of the detector to ^{60}Co and ^{57}Co gamma rays. The enhancement from 72 keV Pb fluorescence is visible in both spectra.

FIG 1

FIG. 2